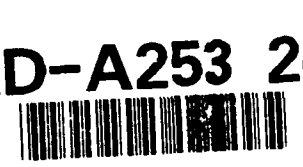

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REPORT

FINAL REPORT

Master Control Unit (MCU)

Low Cost Display (LCD) and

Automatic Valving Systems

for Respiratory

Protection System 21

(RESPO 21)

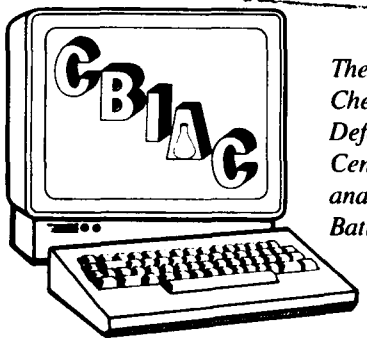
To

U.S. Army Chemical Research,

Development, and Engineering

Center

October, 1990



The Chemical Warfare/ Chemical and Biological Defense Information Analysis Center is a DoD information analysis center operated by Battelle Memorial Institute

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TABLE OF CONTENTS

LIST OF FIGURES

MASTER CONTROL UNIT (MCU), LOW COST DISPLAY (LCD), AND AUTOMATIC VALVING SYSTEMS FOR RESPIRATORY PROTECTION SYSTEM 21 (RESPO 21)

SUMMARY

The primary objective of this program was to assess the feasibility of a master control unit for a respiratory protection system for the U.S. Army Chemical Research, Development, and Engineering Center. The intended function of the master control unit (MCU) includes monitoring physiological, environmental, and system performance conditions and controlling the components of a respiratory protection system to maximize both electrical efficiency and individual protection, yet minimize breathing effort. Instrumentation and sensors for measurement of physiological conditions were evaluated for use in the MCU.

Commercially available positive pressure respiratory protection systems were surveyed and reviewed to determine their relevance for use in the MCU. In order to minimize the effort required to exhale while using a positive pressure respirator it was determined that an automatic valving system would be needed. The purpose of the automatic valving system would be to divert the pressurized air supply during expiration thereby reducing the back pressure on the user. After examining existing respiratory protection systems, we determined that an automatic valving system was not commercially available.

In order to determine feasibility of an automatic valving system, we designed, developed, and fabricated a computer controlled breathing assist model. With a steady simulated breathing input we were able to simulate automatic valving control to minimize breathing resistance yet maintain positive pressure inside the mask.

The breathing assist model demonstrates automatic valving for a given breathing rate input. We believe that it is possible to develop a model that will accommodate automatically the scope of human breathing conditions. During this program we also demonstrated that the programmable computer used to control the breathing assist model could be replaced with a self-contained hardware package.

A brief study was conducted to determine which conditions, that is physiological, environmental, and system performance, would be appropriate for a display unit. An indicator light layout for a low cost display was identified, although due to time and money constraints the unit was not prototyped.

INTRODUCTION

The Chemical Research, Development, and Engineering Center (CRDEC) is entering development of the next generation of respiratory protection known as RESPO 21. Early concept development efforts indicated an immediate need to investigate the use of a master control unit (MCU), a low cost display (LCD), and automatic valving in the prototype design.

The intended purpose of the MCU is to gather data from both external and internal to the respiratory protection equipment. This information may be physiological, pertaining to the health of the user; environmental, monitoring the conditions immediately surrounding the user; and operational, that is, monitoring the performance of the respiratory protection equipment. Some of this data will be sent to the LCD for display while some will be used to monitor and control the respiratory protection equipment at an energy efficient, comfortable, and safe level. The primary objective of the MCU is to maintain a satisfactory protection factor while minimizing breathing resistance.

The LCD is intended to provide visual output indicating the conditions of some of the more pertinent physiological, environmental, and operational information. The LCD could provide warnings for the respiratory protection wearer or information to medical personnel such a vital signs monitoring for emergency situations.

The intent of the automatic valving system is to allow a blower to supply filtered air at some nominal pressure above ambient pressure to the mask corresponding to the breathing demand of the mask wearer. The automatic valving system would divert the pressurized air supply from the mask during exhalation to minimize breathing resistance. The automatic valving system is intended to operate with input from the MCU over the range of breathing conditions. Figure 1 shows a schematic of how the MCU, LCD, and automatic valving system interact with each other and the respiratory protection

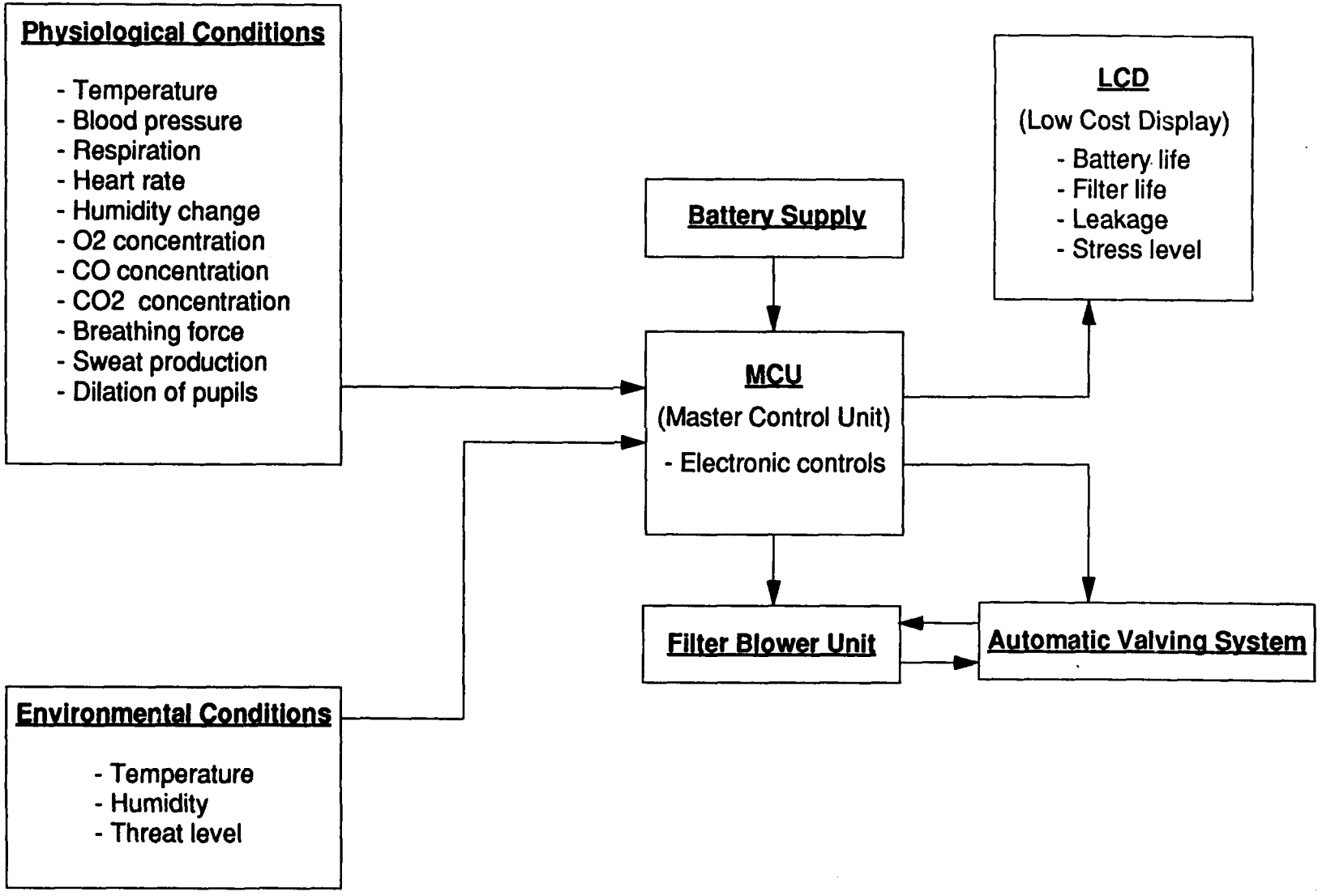


FIGURE 1. SCHEMATIC SHOWING RELATIONSHIP OF MCU, LCD, AND AUTOMATIC VALVING SYSTEM

equipment. Also included in Figure 1 are listings of some of the physiological, environmental, and operational conditions that were determined to be relevant to the MCU.

In addition to the work on this task, there are other programs currently being conducted for the development of RESPO 21. These programs include development of novel seals and attachment mechanisms for respiratory protection equipment and the evaluation of lens defog techniques in a protective mask.

OBJECTIVE

The objective of this task was to evaluate the functions available for incorporation into a master control unit (MCU) for use in the next generation of respiratory protection equipment (RESPO 21). A demonstrator model incorporating these functions, along with a low cost display (LCD) and automatic valving, was to be delivered to the Government for evaluation.

TECHNICAL APPROACH

The technical approach followed to determine the functions of the MCU was organized into two basic tasks. The first task was to evaluate the measurable conditions both externally and internally to the respiratory protection system. The second task was to characterize the components and control of the components that comprise the respiratory protection system.

The conditions to be measured include environmental, physiological, and system performance conditions while the controllable components include the blower and the valving system. Most of the effort to identify the measurable conditions was directed towards the area of the physiological conditions relating to respiratory protection. This area was the one with the least pertinent information for this program. The environmental and system performance conditions required technology and techniques that were more commonly known and practiced that those associated with the physiological conditions.

In general, the determination of the physiological conditions included surveying the pertinent literature, reviewing state-of-the-art sensors, considering how the sensors would be integrated into the mask of

RESPO 21, and investigating environmental, physiological, and system performance conditions. After obtaining all of the above information the findings were summarized with recommendations.

The primary objective of this program was to evaluate functions which could be performed by an MCU. The intended purpose of the MCU was to accumulate information from various sources, synthesize the information, and then control the respiratory system to provide optimum protection. An additional task required of the MCU would be to display, using the LCD, selected information obtained by the MCU to the user or other personnel concerned about the users condition. For example, these personnel might be instructors training the user or medical personnel assessing the users condition.

There is potentially many different kinds of information that could be fed to the MCU for use towards respiratory protection. This information could be concerned with environmental conditions such as ambient temperature, humidity, or threat level; or the information could be the physiological conditions of the user, for example, body temperature, heart rate, and blood pressure to name a few. Knowing the environmental conditions of the surroundings and physiological conditions of the user could provide vital input toward controlling the respiratory system to operate at an efficient level.

Other than environmental and physiological conditions, it may be desirable to obtain feedback on the operating conditions of the respiratory protection system in use. Some examples of this include battery life, filter life, and the amount of leakage into the mask. Information on the operating conditions of the respiratory protection system would provide the mask wearer with valuable logistical input.

The approach taken during this program was to investigate all of the potential physiological conditions and the sensors available and to determine the ease of implementation of these sensors into a respiratory protection ensemble. This approach will be described later in this report. In parallel with this effort it was also necessary to investigate potential hardware, sensors, and controller combinations that would provide a means with which to accomplish an effective and controllable breathing assist model. In this next section, we define the basic components necessary for breathing assist and discuss the development and results of a breathing assist demonstrator unit.

Breathing Assist Demonstrator Unit

Review Requirements

The respiratory protection system is comprised of various components that are designed to provide filtered air at a positive pressure inside of the users mask. The basic components include a blower/filter unit that provides the filtered air at pressure, a valving system that controls the air supplied to the mask during inhalation and diverts the airflow during exhalation, a pressure sensor or similar device that monitors inhaling and exhaling, a controller that receives information from the pressure sensor and controls the valving system and/or blower accordingly, and an accumulator that stores the filtered air during exhalation for use in supplementing the air supplied during inhalation. It should be noted that the accumulator is an optional component pending verification of its effectiveness for various breathing scenarios.

Design and development of a breathing assist demonstrator unit was necessary to provide a means to characterize and evaluate the various components under consideration for both the MCU and the automatic valving system. These components include the sensor required to monitor the breathing cycle, the control valves used to direct and divert the blower generated air supply, and the programmable controller used to operate the valves based on the feedback obtained from the sensor.

Concept Generation

Four conceptual breathing assist scenarios were generated for consideration for a demonstrator unit. Each scenario represents a slightly different approach for diverting the filtered air supply from the mask during exhalation. The four concepts are shown in Figures 2 through 5. A description of the four breathing assist scenarios is given below.

Concept 1: Bag Accumulator

This concept employs a blower/filter unit, a breathing bag, and two check valves or solenoid valves at the inlet and exit of the mask. The blower

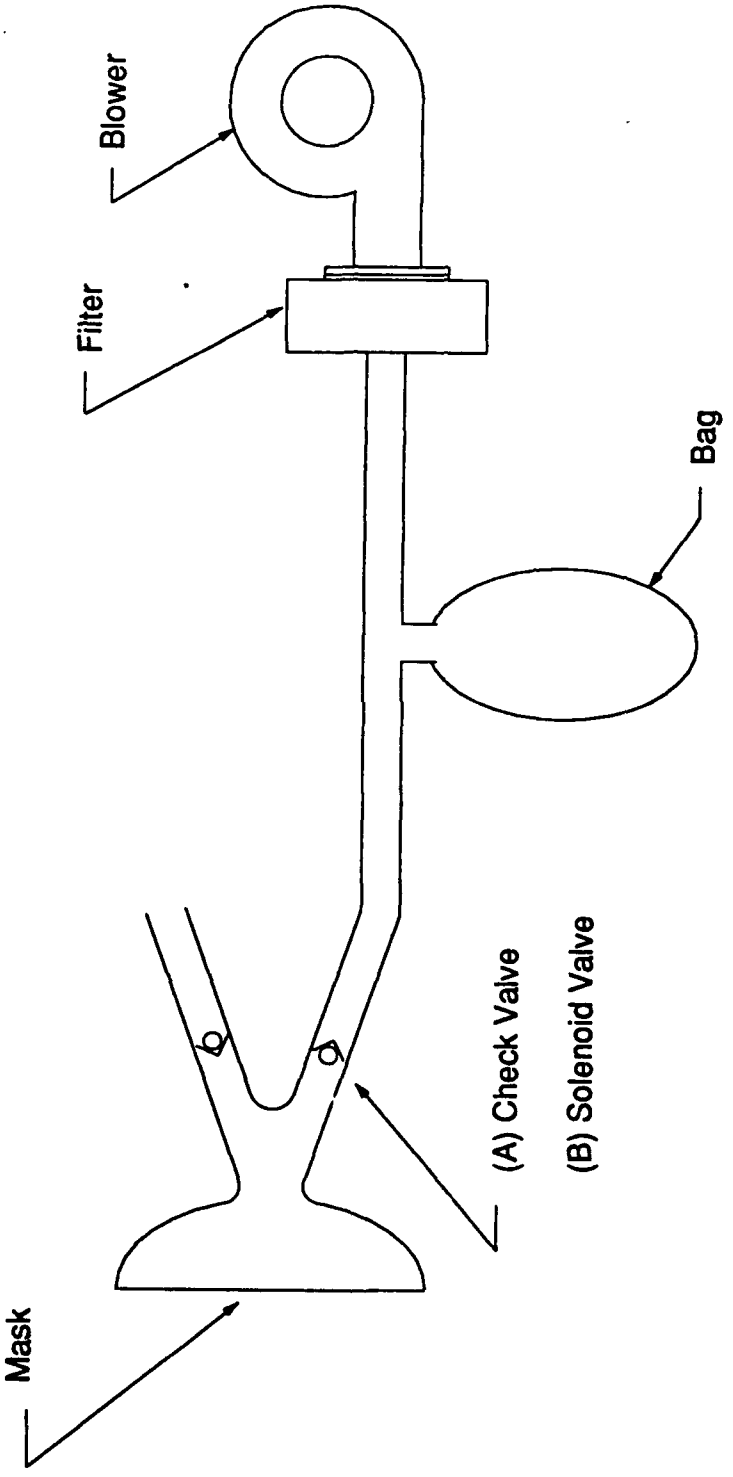


FIGURE 2. BAG ACCUMULATOR

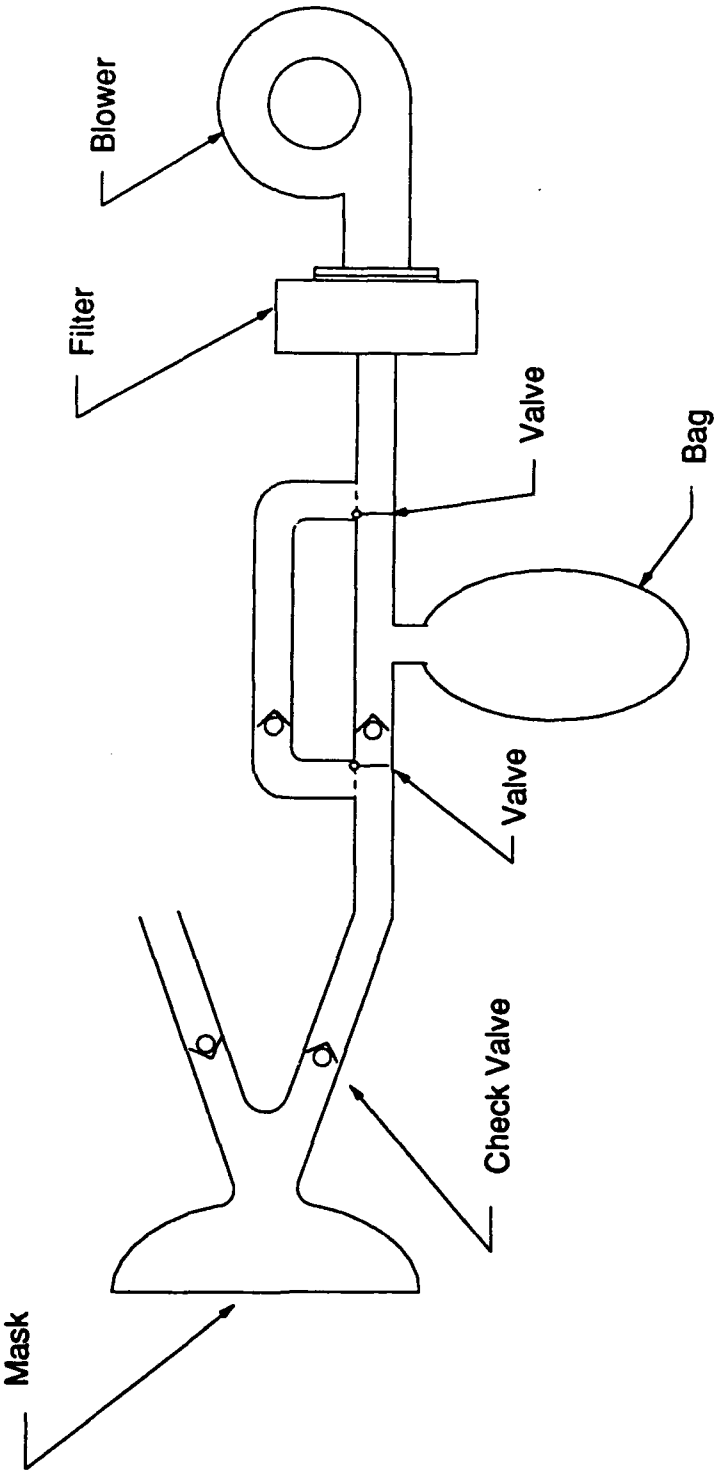


FIGURE 3. BY-PASS VALVE

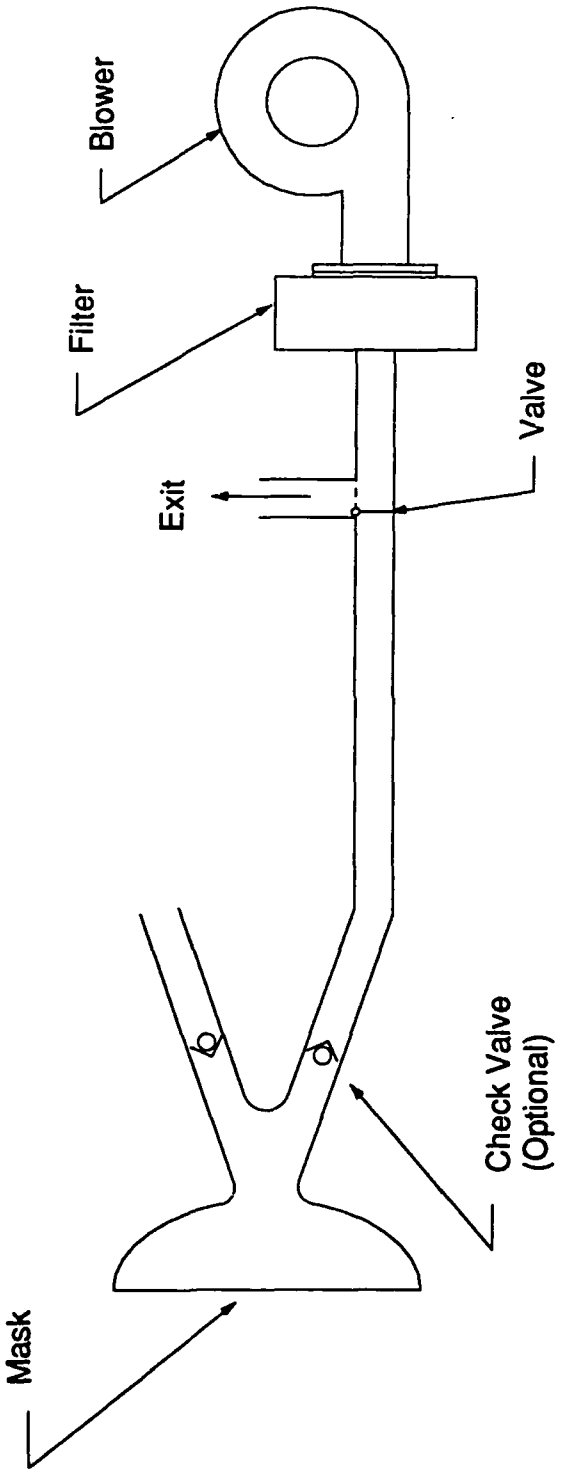


FIGURE 4. DUMPING BY-PASS VALVE

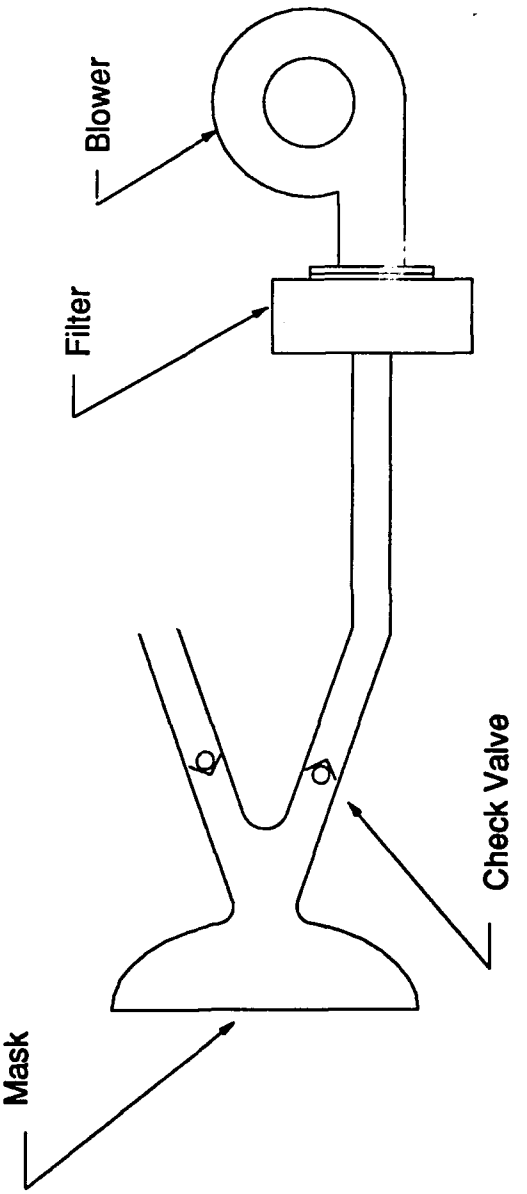


FIGURE 5. CYCLING BLOWER

speed is set to deliver the average amount of air required, while the breathing bag is used to accumulate a volume of filtered air while the mask wearer is exhaling. During inspiration, the blower and breathing bag feed filtered air to the mask to maintain positive pressure within the mask. The breathing history of the mask, via a pressure indicator, is collected at the Master Control Unit (not shown on the diagram) and thus speed changes are made to the blower in response to the average demand over a period of time.

A check valve will be used if the added pressure load on the mask wearer is acceptable, otherwise solenoid valves will be employed. Solenoid valves have the added advantage of being able to open and close flow to and from the mask at desired times within the breathing cycle.

Concept 2: By-Pass Valve

The second concept is similar to the first concept except that instead of placing the breathing bag in series with the blower, the breathing bag is in parallel with a by-pass line. This by-pass line is used during the portion of the breathing cycle when the blower can supply the filtered air demand. During peak inspiration the breathing bag accumulator will supplement flow.

Concept 3: Dumping By-Pass Valve

This approach simply dumps the fresh air supplied by the blower during expiration, thus allowing the mask wearer to close the inspiration check valve during expiration. As in Concept 1, the blower speed is changed due to the pressure history inside the mask. This concept could also be used with a constant speed blower which would provide maximum required delivery. However, this system would be inefficient.

Concept 4: Cycling Blower

The above three concepts utilize continuous blower operation so as to eliminate electronic valves. Concept 4 employs a motor blower that has the ability to cycle on and off, thus only supplying fresh air to the mask during inhalation. This cycling could be done by turning the blower on and off or by

employing a clutch that would engage and disengage the motor from the blower impeller on each cycle.

Identify Components

After reviewing the above concepts, it was decided that the bag accumulator concept (Concept 1) would be the most flexible system and would provide the most information for our feasibility study. The major components required for the bag accumulator concept include a blower/filter unit to supply filtered air for breathing, an accumulator bag to accumulate air during expiration, a solenoid valve that would provide a means to shut-off the air supply electrically, a pressure sensor that would be capable of measuring the pressure inside the mask, and a non-rebreathing valve that would provide a working volume similar to the dead space inside of a mask. Additional components would include switches to control the solenoid valve manually, a programmable computer to provide a means to control the solenoid valve automatically, a strip-chart recorder to record the pressure inside the mask (or non-rebreathing valve representing the mask), and power supplies to power the blower/filter unit and pressure sensor.

The components required to fabricate the breathing assist demonstrator unit came from a variety of sources. The blower/filter unit and miscellaneous hoses were supplied by CRDEC, the pressure sensor, solenoid valve, non-rebreathing valve, and switches were purchased, and the programmable computer, strip chart recorder, a breathing machine and power supplies were supplied from Battelle stocks.

The blower/filter unit used was an ILC Dover Blower Assembly P/N 0083-27414-01, S/N 1498, Contract No. DAAJo9-85-C-B284, Lot No. 002-003. The blower motor component of the ILC Dover Blower Assembly was an EG&G Rotron Part # 011120 , Series 2566 RF , 14000 RPM, 0.59 Amp, 23 Volt. Two filters were used in parallel on the blower/filter unit. The filter is described as a PLC 1986 Canister 02, 4240-21-871-7842, PCT87B002023, WT.262g. The blower/filter unit has an adjustable speed control that can vary the output of the unit from 2 to 6 cubic feet per minute (CFM).

The pressure sensor was purchased from MicroSwitch, a Honeywell Division. The pressure sensor is a 160PC series, catalog number 163PC01D36 with a pressure range of $\pm$ 5 inches of water. The solenoid valves were

purchased from the Automatic Switch Company (ASCO) and is described as a normally closed, low pressure 2-way solenoid valve, Catalog Number 8040C5. This particular valve was selected because it was available with a fairly large orifice size of 1-1/4 pipe, and thus the flow resistance was minimal. Flow restrictions that could cause large pressure drops were eliminated to prevent adversely effecting the control system.

The two-way non-rebreathing valve used to simulate the mask for our demonstrator unit and a 2-liter breathing bag (used as the accumulator) was purchased from Warren E. Collins, Incorporated. Collins is a supplier of pulmonary instruments and accessories. The non-rebreathing valve was made by Hans Rudolph, Incorporated, and the Collins Catalog Number is 021098.

Fabricate and Manually Test Demonstrator Unit

The demonstrator unit components were assembled. A schematic representation of the demonstrator unit is shown in Figure 6. The unit was tested by turning on the blower/filter unit and the breathing machine and manually switching the solenoid valve open and closed as required during the breathing cycle. The solenoid valve was switched on just prior to inspiration and switched off just after expiration. The strip chart recorder was connected to the pressure sensor and data was generated for the manual tests. The results of these tests indicated that it was possible to maintain positive pressure with the demonstrator unit yet minimize breathing resistance during expiration. Figure 7 shows a portion of the strip chart recorder data documenting our results with manual switching of the solenoid valve.

Add Programmable Computer

The next step was to add a programmable computer to the demonstrator unit. The programmable computer was used to compare the pressure sensor readings during the breathing cycle to pre-set limits corresponding to when the solenoid valve should open and close. These limits were determined by operating the breathing assist device manually and measuring the points where the valve is switched.

A block diagram showing the relationship of the above components is located in Appendix A. The solenoid valve is switched via a solid-state relay added to the demonstrator unit. A low pass filter was added to reduce the

DEMONSTRATOR UNIT

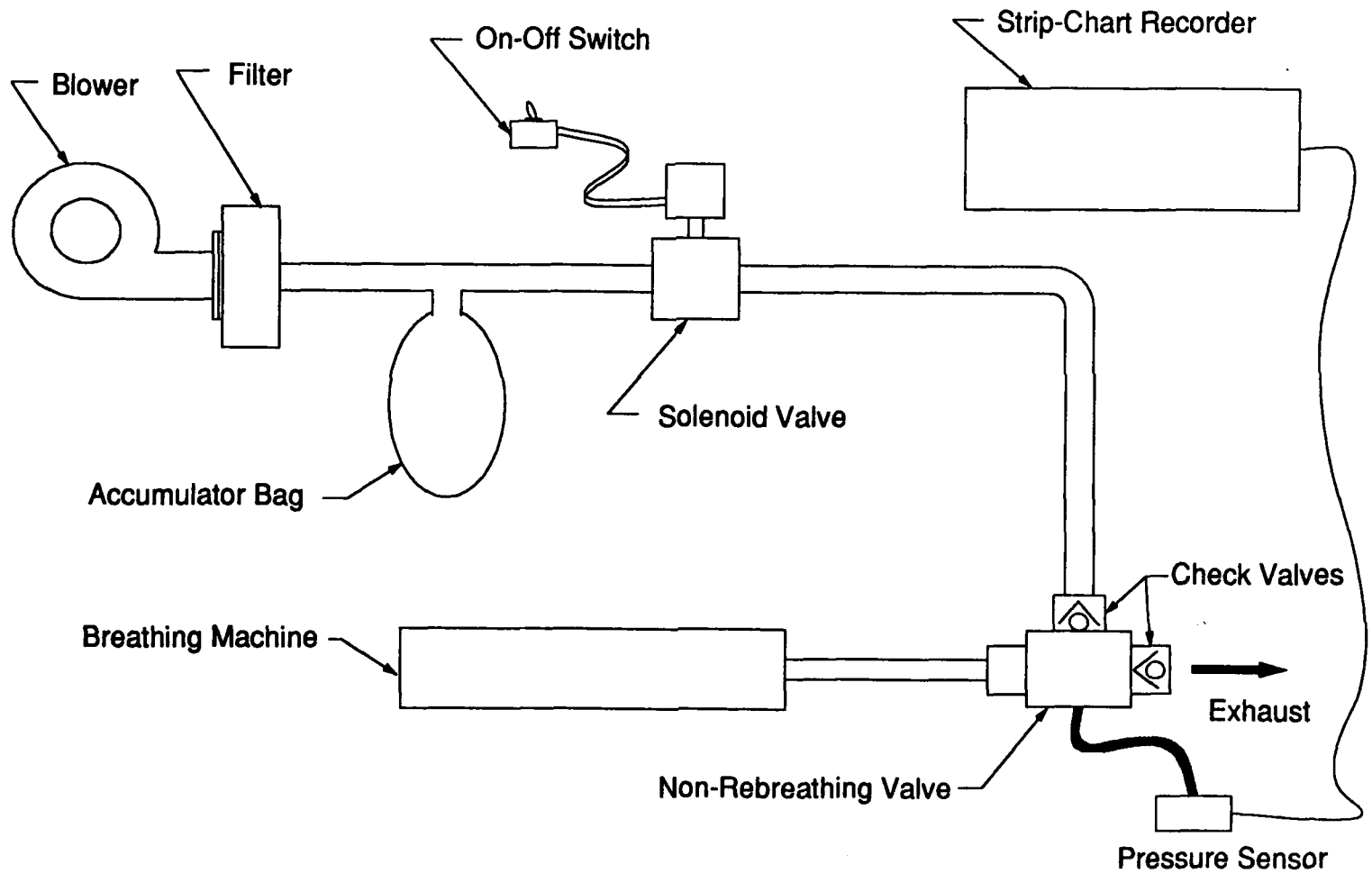


FIGURE 6. SCHEMATIC OF DEMONSTRATOR UNIT WITH MANUAL SWITCH FOR SOLENOID VALVE

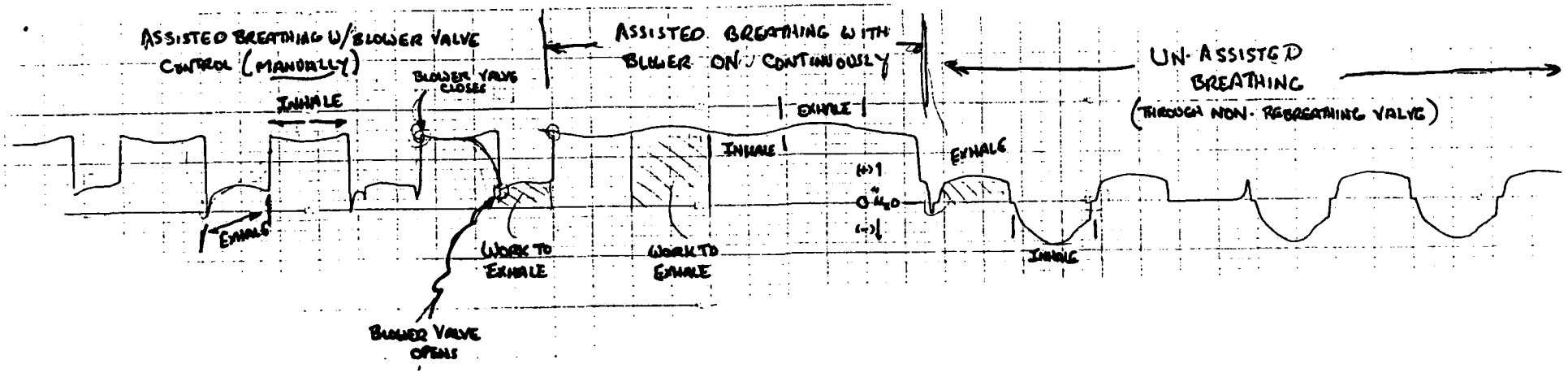


FIGURE 7. STRIP CHART RECORDER OUTPUT DOCUMENTING MANUAL SWITCHING OF SOLENOID

electric noise inherent in the signals obtained from the pressure sensor. A printout of the program used to automatically switch the solenoid valves with input from the pressure sensor is located in Appendix A.

The results of the tests conducted with the programmable computer are shown on a strip chart (see Figure 8). These tests include running the blower filter unit only, running the breathing machine at an "at rest" breathing rate of approximately 15 breaths per minute with no blower or automatic valving, running the breathing machine with blower only, and running the breathing machine with blower and automatic valving. The zero or ambient pressure is indicated on the chart. The chart documents that the automatic valving helps minimize breathing resistance yet also maintains positive pressure throughout the breathing cycle.

During the development of the computer program used to control the solenoid valve, it was discovered that spikes would occur on the strip chart recorder when the solenoid valve was opened and closed. These spikes would cause the control system to oscillate and thus prevent the valves from operating as intended. In order to allow the valves to stay open or closed when a pre-set pressure was reached, it was necessary to put into the program slight time delays that would allow the spike to occur without the control of the valve going unstable.

After the system was operated satisfactorily with the breathing machine simulating breathing at rest, human breathing was tested. The result of the human input was favorable. Although the system was difficult to use due to the length of hoses used and the non-rebreathing valve used in place of a mask, the output showed that the valve was changing, automatically reducing the effort of exhalation, and the pressure measured inside the non-rebreathing valve stayed positive. The results of the human breathing tests are shown in Figure 9.

Breathing Control System

To provide a degree of automation in the experimental breathing apparatus, we implemented a simple control system which switches power to the valves in response to the user's breathing pattern. Information for determining the user's breathing pattern is derived from a pressure sensor in the mask portion of the apparatus. The control system was implemented in two

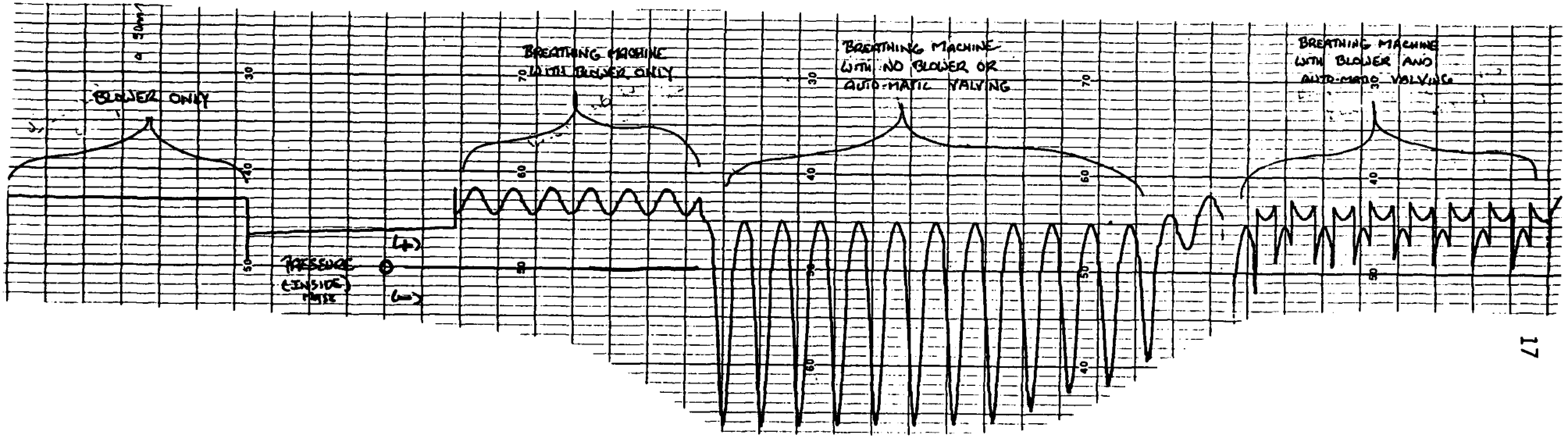


FIGURE 8. STRIP CHART RECORDER OUTPUT DOCUMENTING AUTOMATIC SWITCHING OF SOLENOID VALVE WITH PROGRAMMABLE COMPUTER

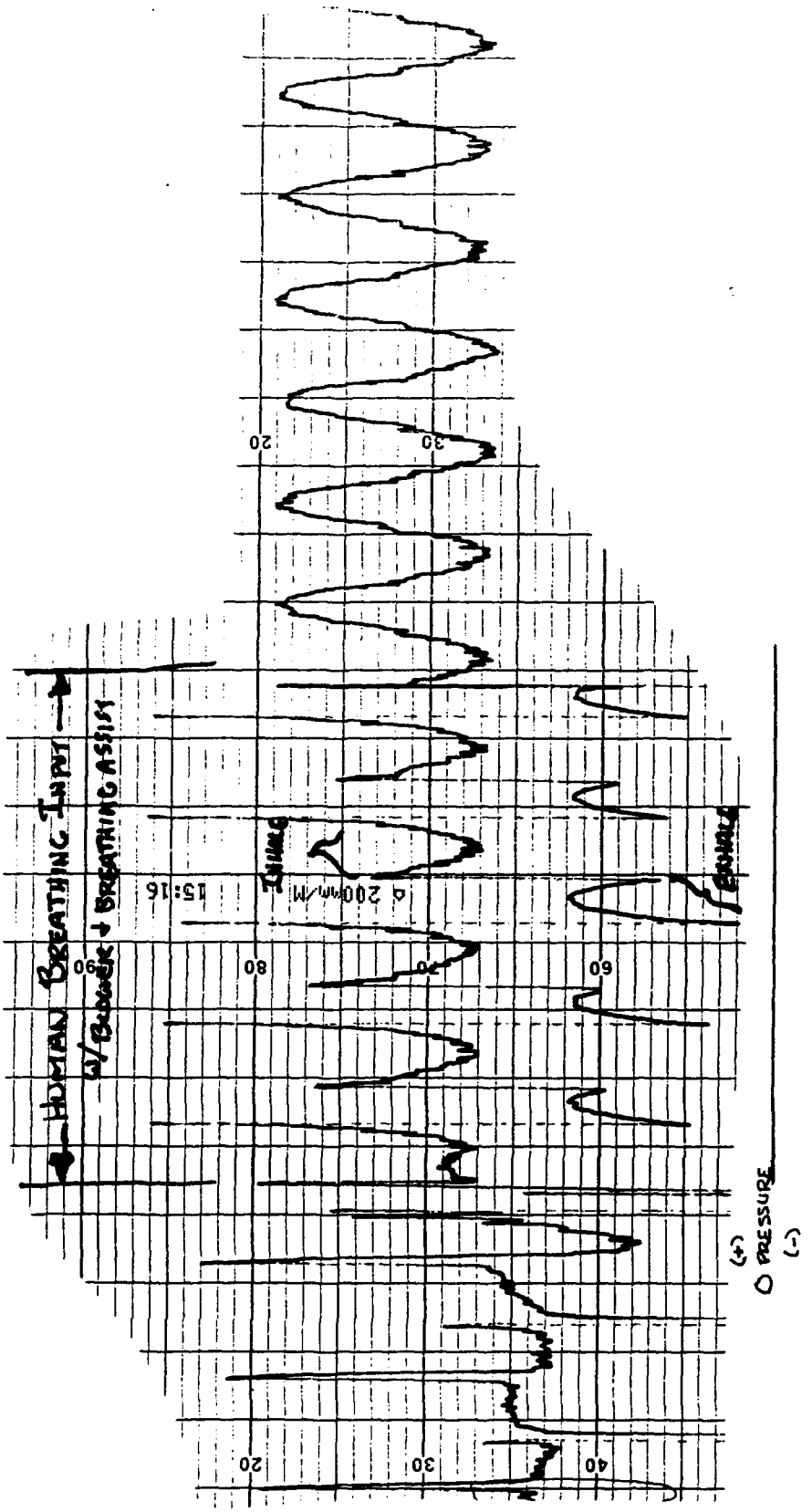


FIGURE 9. STRIP CHART RECORDER OUTPUT DOCUMENTING AUTOMATIC SWITCHING OF SOLENOID VALVE WITH HUMAN BREATHING INPUT

forms, in software running on a desktop computer and in a self-contained hardware package. The computer-based implementation was built to provide more flexibility for experimentation, which will be necessary in future work for accommodating human breathing as opposed to the machine breathing currently supported.

A block diagram of the computer-based system and the software listing are included in Appendix A. In the same Appendix is a copy of the schematic for the hardware implementation.

Future development of the control logic will probably occur in concert with further refinement of the breathing circuit and the equipment used to implement it. More complex sensing and decision-making will almost certainly be required to accommodate differences from person-to-person, as well as differences due to the dynamically varying breath rate and tidal volume of an active human breather. For these control investigations, the computer-based implementation will be invaluable. The design of the basic software was developed with future expansion in mind, and will support a variety of experiments with simple modification.

The pressure sensor used in our demonstrator unit provided a means to monitor timing within the breathing cycle. We found that the variations in pressure sensed inside the mask changed very slightly, and that accuracy of valve timing depended on the ability to detect pre-set threshold limits within the breathing cycle. For this reason we investigated an alternative method to sense the breathing cycle.

Alternative Breathing Sensor

Experiments with a simple sensor which could detect the mask wearer's breathing pattern directly were also conducted. These experiments used a small strip of a piezoelectric polymer, PVDF, placed in the mask near the nose. Breathing caused the PVDF strip to flex slightly from the motion of the air, producing an electrical signal. Since it is the timing of the signal that is valuable for breathing apparatus control, any variations in signal amplitude can be ignored, resulting in a simplified circuit. Tidal volume could conceivably be estimated from the sensor signal by monitoring the amplitude of the deflection signal and integrating over the time between direction reversals, but this information can be corrupted by amplitude

differences due to temperature. PVDF is responsive to changes in temperature as well as to deflection, so with different ambient temperatures in the mask the change in temperature relative to the nearly consistent temperature exhaled air would vary. This might be compensated for by measuring the temperature inside the mask, but the additional complexity of the system starts to become unwieldy and of questionable value.

The basic breath-timing sensor can probably be refined into a device which would be useful either for providing the basic timing signal for breathing control, or perhaps as a backup signal used to automatically check the operation of a separate basic sensor. It has the advantages of very low cost and, since it measures air motion rather than pressure, an independent source of information.

Physiological Sensing

An active soldier in MOPP 4 is subject to a severely stressful situation. In addition to the threat of chemical attack from a variety of possible agents, there is the thermal burden of the protective equipment, and the additional psychological stresses imposed by restricted vision and hearing. Since the combat environment alone can be overwhelming, the addition of these serious stress factors results in an increased likelihood of disfunction in troops. When a person in MOPP 4 is disabled, the protective gear obscures many of the indicators which medics use to diagnose his condition. With all of this as background, it is reasonable to consider the use of some type of physiological sensing in the RESPO 21 mask. Such sensors could be used to detect, and perhaps even to predict, a stress-induced casualty.

The investigation of physiological sensing was conducted in two stages. First, the physiological indicators were identified which might be measured to provide an indication of the soldier's condition. the capabilities of commercially available physiological sensors were investigated, primarily in the medical market, which might be applicable to implementation in a next-generation mask.

Results from these investigations are presented in the following paragraphs. The complete data from the survey is provided in Appendix B.

Physiological Indicators

Many physiological parameters change as the environment surrounding a given individual is altered. Examples include changes in temperature, humidity, levels of mental stress, and levels of exertion. The human system is designed to maintain internal stability, within certain limits, as external conditions are altered. Non-invasive monitoring of various physiological parameters, when combined with knowledge about the environment, can yield information which can be used to assess whether or not the body is successfully maintaining internal stability. This approach to observing physiological status may be applied in the area of military gas masks, affording an early warning to the user of possible exposure to chemical agents in the environment. Such a system might incorporate a microprocessor to obtain and analyze data collected from a suite of physiological sensors.

A sample of physiological parameters, and the way in which they change in response to altering environmental conditions, is outlined below:

1. Increased cardiac output, for any number of reasons, causes increased numbers of capillaries in the lungs to open up.

2. Arterial pressure = Cardiac output x total peripheral resistance.

3. The respiratory system regulates acid-base balance by forming carbonic acid from CO_2 and H_2O. As ventilation increases, CO_2 decreases and vice versa.

4. The anteroposterior diameter of the chest increases approximately 20 percent during inspiration.

5. The oxygen transport from the lungs to the tissues can be increased five fold by an increase in cardiac output and three fold by an increase in the tissue utilization coefficient for O_2.

6. The level of CO_2, which is a primary end product of metabolism, is carefully controlled by several body systems.

There are many other coupled events taking place in the body to maintain stability. Effective measurement of external parameters which would indicate whether the above processes are occurring in a normal fashion could be combined to provide the early warning system needed for battlefield gas masks.

Some physiological parameters which could potentially be measured from within a gas mask system might include:

1. Rate of respiration
2. Blood pressure
3. Heart rate
4. Change in humidity of inspired versus expired air
5. Change in O_2 concentration of inspired versus expired air
6. Change in CO concentration of inspired versus expired air
7. CO_2 concentration of inspired versus expired air
8. Change in force of inspiration and expiration
9. Change in temperature of inspired versus expired air
10. Rate of sweat production
11. Dilation of pupils.

Measurement of the above parameters might be performed using various combinations of the following techniques:

1. Pressure pulse measurement using an earlobe clip with piezoelectric pressure transducer

2. Blood oximetry measurement using an earlobe clip which transmits a light beam through the lobe and records the energy which passes through

3. A valved ventilation system which provides a separate path for inhaled and exhaled air. Sensors could be located in the pathways for the measurement of humidity, temperature, O_2 concentration, CO concentration, and CO_2 concentration

4. Respiration rate may be determined by monitoring the valve actuation of the gas mask

5. Inspiratory and expiratory force may be measured by propellers placed in the airways of the mask, or by the pressures exerted on pliable venturies

6. Measurement of pupil dilation might be gauged using the measured refraction of low power laser light which has been directed into the eyes of the user

7. A moisture sensor could be placed into a headband, which is an integral part of the gas mask apparatus

8. Heart rate, and possibly blood pressure, could be measured using the earlobe clips as in (1) and (2) above

9. Chest expansion may be measured using a strain gauge of some form. This would yield data regarding breathing rate, force of effort, and possibly tidal volumes.

Commercially Available Physiological Sensors

The commercial medical marketplace has been the site of intense development activity for a number of years, and with the impetus of the aging population, this will continue. Many of the physiological parameters of potential use in a gas mask are also measured for more routine medical purposes, which has produced a variety of sensors which might be applicable to the mask. Of course, the hospital environment does not force a sensor to be small enough to fit in a mask, or to be battery powered, but some products may be intended for use in portable equipment or simply be small by the nature of the technology used.

For this project, we surveyed the commercial marketplace for sensing techniques and products which measured the physiological parameters named above as the most potentially useful in the mask. Sources of information included Battelle files, personal files, open literature, and telephone conversations with vendors.

As a capsule summary of the results, it appears that sensing the percent CO_2 in the exhaled air is both feasible with existing sensors and physiologically useful. The circuitry which supports the basic sensor would have to be both hardened and significantly reduced in size, but these are both reasonable within the current state of the art in electronics. The respiration rate is likely to be sensed as part of the active breathing control function, so it would be available for extracting stress information as well.

A summary of the results of the survey of commercially available sensors, and an evaluation of their potential for use in a mask is included in Appendix B.

Low Cost Display

After investigating the physiological, environmental, and system performance conditions for use in the MCU, we determined that there were particular areas of interest that would be appropriate for display on the LCD. These areas include the following:

- Stress Indicator Light
- Battery Life Indicator Light
- Pressure Drop Indicator Light
- Threat Light
- Protection vs Breathing Assist Switch
- Filter Life Indicator Light.

Figure 10 shows a potential layout for the LCD incorporating the above indicators. A prototype of the above described layout was not fabricated due to time and cost limitations. It is anticipated that the proposed layout could be easily fabricated with commonly available electrical components. Providing sensor input for each of the indicator lights may be somewhat complicated for some of the above conditions. For example, the stress indicator light needs input from several physiological, environmental, and system performance sensors. Also, a small sensor for the threat light is not currently available. The remaining conditions are anticipated to be relatively simple to implement.

CONCLUSIONS

We can test and analyze a variety of functions with the current test set-up (demonstrator unit) operated from a programmable computer. Minor changes and modifications to the demonstrator unit will enable us to analyze both electrical efficiency and breathing efficiency to support automatic valving conceptual development. The solenoid valve used for the present demonstrator unit exhibits characteristics that make fine tuning difficult. These characteristics include the inability to control the speed of opening and closing, as well as the degree to which the valve opens and closes. For

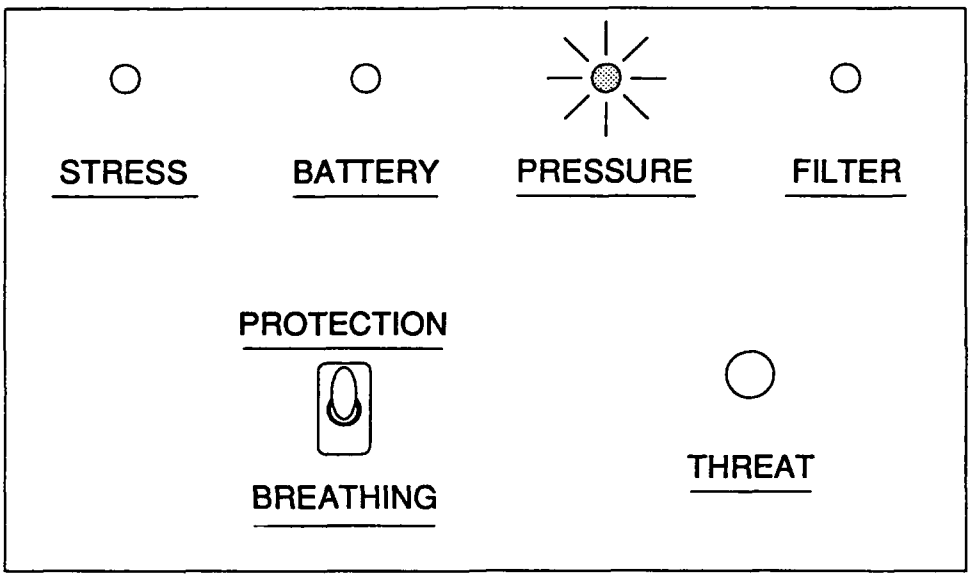


FIGURE 10. PRELIMINARY LAYOUT OF LCD

future work, it would be desirable to develop a valve that provides adjustment in these areas.

Many functions can be obtained for control of RESPO 21 and for display. The LCD can be fabricated with simple electronics. The automatic valving system requires additional data before a consensus can be found regarding feasibility for a variety of breathing conditions.

RECOMMENDATIONS

The feasibility of the automatic valving should be thoroughly analyzed before further development of valving schemes are initiated. Further study, data, and analysis are necessary to prove feasibility. It is recommended that a control valve be developed and fabricated that will provide control of the speed of actuation as well as the degree of opening and closing. The data generated on this program indicated that control of the valve functions would further enhance the stability of the automatic valving system for the complete range of breathing conditions.

APPENDIX A

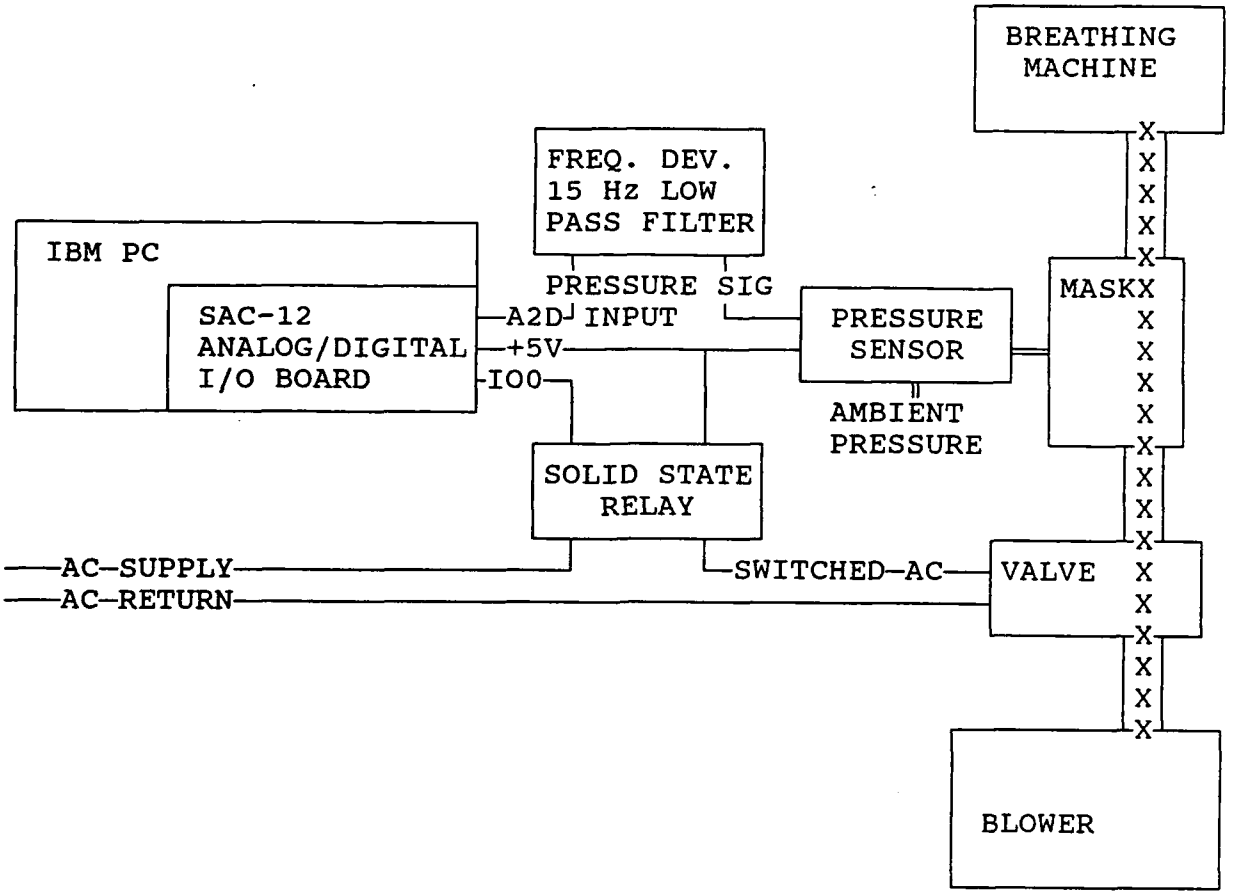
BREATHING ASSIST DEMONSTRATOR UNIT

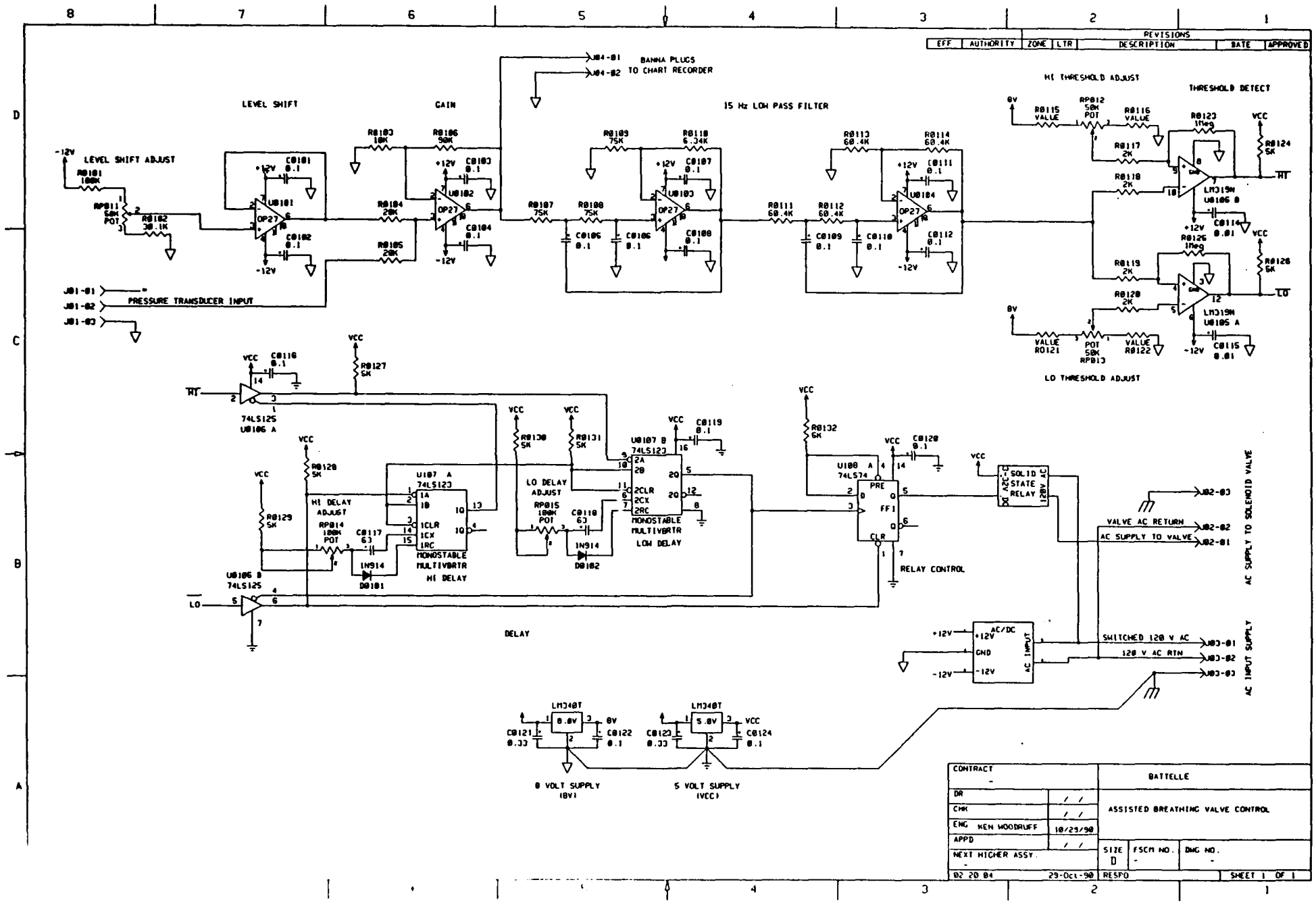
COMPUTER PROGRAM
SYSTEM SCHEMATIC
ELECTRICAL SCHEMATIC

Program for PC-Operated Valve Control

```
#include <stdio.h>
#include <time.h>
#include <dos.h>
#include <bios.h>
#include <math.h>

#define PRESSURE 0          /* ADC channel defs */
#define SAC 0x300           /* SAC board addresses */
                            /* SAC+0 READ ADC STATUS, WRITE CONTROL  */
#define A2D_DATA SAC+1      /* SAC+1 ADC DATA , CONVERT */
#define A2D_RST SAC+2       /* SAC+2 ADC RST,CAL, DAC LO  */
#define STAT SAC+3     /* SAC+3 BOARD STATUS, DAC HI  */
#define T0 SAC+4       /* SAC+4 TIMER 0, TIMER 0 */
#define T1 SAC+5       /* SAC+5 TIMER 1, TIMER 1 */
#define T2 SAC+6       /* SAC+6 TIMER 2, TIMER 2 */
#define TCTRL SAC+7    /* SAC+7 undefined,TIMER CONTROL */
#define MAX_SET 25     /* Setpoint for max pressure value--close valve */
#define MIN_SET 5      /* Setpoint for min pressure value--open valve  */
#define ON_DELAY 10    /* Delay time (clk ticks) after valve open */
#define OFF_DELAY 10 /* Delay time (clk ticks) after valve closed */

static int HIGH = 2830;
static int LOW =  2790;

static int base_val = 0x10;
static int delay_val = 10;
static FILE *stream;

main()
    {
    long time;
    char a, change_valve=0;
    char fw=0;
    int delay;
    char on = 1;
    unsigned cvrt,min,max;

    /*  ask to change  HIGH and LOW setpoints */
    printf("Current setpoints are HIGH = %d, LOW = %d\n",HIGH,LOW);
    printf("Do you want to change switching setpoints? (y/n):  ");
    a = bioskey(0)& 0xff;
    printf("%c\n",a);
    if(a == 'y' || a == 'Y')
        {
        printf("Please enter new HIGH setpoint:  ");
        scanf("%d",&HIGH);
        printf("Please enter new LOW setpoint:  ");
        scanf("%d",&LOW);
        }
      else printf("\n");
```

```
Program for PC-Operated Valve Control

printf("Do you want output in a file? (y/n);  ");
    a = bioskey(0)& 0xff;
    if(a == 'y' || a == 'Y') fw = 1;
    printf("%c\n",a);
/*   printf("How many clock ticks do you want to delay?  ");
    scanf("%d",&delay);
    fw = 0;*/
    delay = 10;
    if(fw) stream = fopen("DATA.PRN","w");  /* open file for writing */
    inportb(A2D_RST);          /*  Reset and Calibrate A/D */
    outportb(SAC,0x10);  /*  D0 high to close valve */
    inportb(SAC+2);      /*  Reset and calibrate A2D */
    printf("Resetting and calibrating \n");
    while((inportb(SAC) & 0x80) && !bioskey(1))
    printf("Waiting for calibration \n");
    do
        {
        min = 0xffff;
        max = 0;
        while (!(change_valve) && !bioskey(1))  /*wait for keypressed */
          {
          outportb(A2D_DATA,0);  /* initiate conversion */
                                 /* wait for end of conversion */
          while((inportb(SAC) & 0x8)&& !bioskey(1));
          cvrt = inportb(A2D_DATA) * 16;  /* get conversion msb */
          cvrt += inportb(A2D_DATA) / 16; /* get conversion lsb */
          if (cvrt > max) max = cvrt;
          if (cvrt < min) min = cvrt;
          if ((cvrt > HIGH) && !on) change_valve = 1;
          if ((cvrt < LOW) && on) change_valve = 1;
          if (fw) fprintf(stream,"%6d, %6d, %6d %d\n",min,max,cvrt,on);
          printf("min = %6d, max = %6d, cvrt = %6d\n",min,max,cvrt);
          }
        if (bioskey(1)) a = bioskey(0);
        if(on)
            outportb(SAC,0);
          else
            outportb(SAC,0x10);
        on = !on;
        change_valve = 0;
        printf("max = %d, min = %d, valve = %d \n",max,min,on);
        time = biostime(0,0l)+delay;      /*  Delay time  */
        while(biostime(0,0l) < time);
        min = 0xffff;
        max = 0;
        }
        while(a != 'q');
    if (fw) fclose(stream);
    printf("Current setpoints are HIGH = %d, LOW = %d\n",HIGH,LOW);
    outportb(SAC,0);
    }
```


BREATHING MACHINE
FREQ. DEV. 15 Hz LOW PASS FILTER
IBM PC
SAC-12 ANALOG/DIGITAL I/O BOARD
PRESSURE SIG
A2D INPUT
+5V
IOO
PRESSURE SENSOR
MASK
AMBIENT PRESSURE
SOLID STATE RELAY
AC-SUPPLY
AC-RETURN
SWITCHED-AC
VALVE
BLOWER


REVISIONS
EFF | AUTHORITY | ZONE | LTR | DESCRIPTION | DATE | APPROVED
J04-01
J04-02
BANNA PLUGS
TO CHART RECORDER
LEVEL SHIFT
GAIN
15 Hz LOW PASS FILTER
HI THRESHOLD ADJUST
THRESHOLD DETECT
LEVEL SHIFT ADJUST
R0101 100K
RP011 50K POT
R0102 30.1K
U0101
U0102
U0103
U0104
OP27
C0101 0.1
C0102 0.1
C0103 0.1
C0104 0.1
C0105 0.1
C0106 0.1
C0107 0.1
C0108 0.1
C0109 0.1
C0110 0.1
C0111 0.1
C0112 0.1
R0103 10K
R0104 20K
R0105 20K
R0106 50K
R0107 75K
R0108 75K
R0109 75K
R0110 6.34K
R0111 60.4K
R0112 60.4K
R0113 60.4K
R0114 60.4K
+12V
-12V
J01-01
J01-02
J01-03
PRESSURE TRANSDUCER INPUT
RP012 50K POT
R0115 VALUE
R0116 VALUE
R0117 2K
R0118 2K
R0119 2K
R0120 2K
R0121 VALUE
R0122 VALUE
RP013 50K POT
R0123 1Meg
R0124 5K
R0125 1Meg
R0126 5K
LM319N
U0106 B
U0105 A
C0114 0.01
C0115 0.01
8V
VCC
HI
LO
HI THRESHOLD ADJUST
LO THRESHOLD ADJUST
C0116 0.1
R0127 5K
74LS125
U0106 A
R0128 5K
R0129 5K
HI DELAY ADJUST
RP014 100K POT
C0117 63
1N914
D0101
U0107 A
74LS123
MONOSTABLE MULTIVBRTR
HI DELAY
U0106 B
74LS125
LO
R0130 5K
R0131 5K
LO DELAY ADJUST
RP015 100K POT
C0118 63
1N914
D0102
U0107 B
74LS123
MONOSTABLE MULTIVBRTR
LOW DELAY
C0119 0.1
DELAY
R0132 6K
U0108 A
74LS74
PRE
FF1
CLR
RELAY CONTROL
C0120 0.1
SOLID STATE RELAY
VALVE AC RETURN
AC SUPPLY TO VALVE
J02-03
J02-02
J02-01
AC SUPPLY TO SOLENOID VALVE
AC/DC
AC INPUT
SWITCHED 120 V AC
120 V AC RTN
J03-01
J03-02
J03-03
AC INPUT SUPPLY
LM340T
8.0V
5.0V
C0121 0.33
C0122 0.1
C0123 0.33
C0124 0.1
8 VOLT SUPPLY
(8V)
5 VOLT SUPPLY
(VCC)
CONTRACT
-
BATTELLE
DR
CHK
ENG KEN WOODRUFF 10/29/90
APPD
ASSISTED BREATHING VALVE CONTROL
NEXT HIGHER ASSY.
-
SIZE D
FSCM NO. -
DWG NO. -
02 20 04
29-Oct-90
RESPO
SHEET 1 OF 1

APPENDIX B

PHYSIOLOGICAL SURVEY DATA

BIOLOGICAL FUNCTION: Heart rate

DIAGNOSTIC VALUE

- Reflects cardiovascular efficiency and circulatory status.
- May signal conditions of overexertion, fatigue, shock, trauma, and blood loss.

STATE OF THE ART

- **Pulse oximetry:** Photoelectric pick-up from finger, toe, earlobe, or forehead sensor using peripheral blood pulse.
- Cordless chest sensor monitors and transmits ECG pulse to wristwatch unit.
- **Penaz method:** Small cuff wrapped around finger or thumb consists of LED and photodetector to monitor finger artery size. Bladder within cuff controls artery size.

BIOLOGICAL FUNCTION: CO2

DIAGNOSTIC VALUE

- Reflects respiration efficiency, alveolar ventilation, and metabolic and circulatory status.
- May be used to assess airway patency.
- May signal conditions of hypercapnia, hypoxia, and shock.

STATE OF THE ART

- **Capnography:** Noninvasive measurement of CO2 concentration during each insp/exp cycle.
  - (a) **IR Absorption.** Miniature IR sensor placed in airway. IR absorption is proportional to CO2 concentration.
  - (b) **Mass Spectrometry.** Sample of air is aspirated and CO2 molecules are identified by their charge to mass ratio.
  - (c) **Raman Scattering.** Sample of air is aspirated and CO2 concentration is determined by the amount of LASER light scattering.

- **Transcutaneous CO2.** A tc electrode incorporates a miniature heating element that warms the skin under the measurement site. Resulting vasodilation opens the capillaries and closely approximates levels of CO2 to arterial levels.
  Size of the electrode is roughly 1" and is attached to user by a double-sided adhesive disk using an aqueous solution as a contact medium.

BIOLOGICAL FUNCTION: Respiration rate

DIAGNOSTIC VALUE

- Reflects respiration efficiency and alveolar ventilation.
- May be used to reflect pressure changes within mask.
- May signal conditions of fatigue and overexertion.

STATE OF THE ART

- Miniature piezoelectric polymer (PVDF) sensor placed in airway. PVDF is displaced by inspired and expired air.
- PVDF sensor attached to user's chest is deformed with each insp/exp cycle.
- **Spirometry.** Air turbine sensor with titanium vane and galvano-magnetic pick-up element placed in airway. Turbine rotation is counted to determine respiration rate.
- Capacitive sensor attached to user's chest detects shift in center of gravity of upper body iscera with each insp/exp cycle.

BIOLOGICAL FUNCTION: Blood oxygen saturation (HbO2/Sat).

DIAGNOSTIC VALUE

- Reflects respiration efficiency, alveolar ventilation, and metabolic and circulatory status.
- May be used to assess airway patency.
- May signal conditions of hypoxia which can prevent damage to brain and other vital organs.

STATE OF THE ART

- **Pulse oximetry.** Ratio of red to IR absorption across a pulsating capillary bed is proportional to percent oxygen saturation. Sensors available for forehead, temple, finger, toe, and earlobe.
- **Transcutaneous O2.** A tc electrode incorporating a miniature heating element warms the skin under the measurement site. Resulting vasodilation opens the capillaries and closely approximates tissue levels of O2 to arterial levels.

BIOLOGICAL FUNCTION: Blood pressure

DIAGNOSTIC VALUE

- Reflects circulatory status.
- May signal conditions of shock, trauma, hypothermia, hyperthermia, and blood loss.

STATE OF THE ART

- **Penaz method.** Small cuff wrapped around finger of thumb consists of LED and photodetector to detect finger artery size. Bladder within cuff controls artery size. A servo control circuit monitors changing arterial pressure and controls the artery size by adjusting the pressure in the cuff.
- Intermittent occlusive oscillometric method.

BIOLOGICAL FUNCTION: Expired air volume and air flow rate

DIAGNOSTIC VALUE

- Identifies and quantifies lung mechanics, thereby assessing the lung's ability to (1) pump efficiently and (2) oxygenate the blood.

STATE OF THE ART

- **Turbine pneumotachs:** Air turbine sensor with titanium vane and galvano-magnetic pick-up. Turbine rotation is counted to determine flow rate and volume is determined by integrating flow rate. Sensor size is approximately 2" square.

- Volume displacement bellows
- **Fleisch pneumotachs:** Bundle of capillary tubes provide a fixed resistance to airflow. Small openings on either end of the capillary tubes are used to measure the pressure difference created when user breathes through the pneumotach.